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Biometric Emotion Assessment and Feedback in an Immersive Digital Environment

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Abstract Affective computing has increased its significance both in terms of academic and industry attention and investment. Alongside, immersive digital environments have settled as a reliable domain, with progressively inexpensive hardware solutions. Having this in mind, the authors envisioned the automatic real-time user emotion extraction through biometric readings in an immersive digital environment. In the running example, the environment consisted in an aeronautical simulation, and biometric readings were based mainly on galvanic skin response, respiration rate and amplitude, and phalanx temperature. The assessed emotional states were also used to modify some simulation context variables, such as flight path, weather conditions and maneuver smoothness level. The results were consistent with the emotional states as stated by the users, achieving a success rate of 77%, considering single emotions and 86% considering a quadrant-based analysis.

Keywords Emotion assessment · Biometric readings · Immersive digital environments · Aeronautical simulation

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1 Introduction

The presence of dissimulated sensors, actuators and processing units in unconventional contexts is becoming consistently inexorable. This fact brings to both academic and industrial stages the term of Ubiquitous Computing as a regular term. Moreover, constant technology advances have permitted hardware miniaturization and wireless communication capabilities. In a parallel, yet complementary line, Affective Computing has recently gained the attention of researchers and business organizations worldwide. As a common denominator for these two concepts resides Emotion Assessment. Although this topic is no novelty by itself, it has been rediscovered in light of the mentioned knowledge areas breakthroughs, as it became theoretically possible to perform real-time minimal-invasive user emotion assessment based on live biosignals at economically feasible levels.

Having the above mentioned in mind, the authors envisioned an integrated multimedia fully bidirectional interactive system where system's parameters were directly changed accordingly to user's emotional response. The real-time automatic emotion assessment achieved with low intrusion levels is of great importance for social robotics as it would surely potentiate both physical and ubiquitous interaction. As a practical example, a robot capable of perceiving its human interlocutor's emotions would be able to take more suitable decisions and actions, both for therapy and entertainment purposes [1]. As for ubiquitous interaction, such system capability would provide the ability of generating intelligent environments that would fit the user's emotional states [2]. As the running example in this paper, an immersive aviation-based environment was considered. The main reasons behind this decision are related to the human fascination for everything related to flying. However, and as with most things, this attraction co-exists with the fear of flying usually referred to as pterygophobia [3]. According to a poll by CNN and Gallup for the USA Today in March 2006, 27% of U.S. adults would be at least somewhat fearful of getting on an airplane [4].

By using the briefly described multimedia system, the authors were able to provide distinct practical scenarios to apply in several situations that range from traditional entertainment applications, through immersive realistic animations contextualized with user's emotions, to therapeutic phobia treatment.

The project achieved rather transversal goals as it was possible to use it as a fully functional testbed for online biometric emotion assessment through galvanic skin response, respiration rate and amplitude and phalanx temperature readings fusion and its incorporation with Russell's Circumplex Model of Affect [5] with success rates of around 77% considering specific regions in Russell's model, and 86% when combining the regions into the four quadrants present in the model. A successful emotion assessment engine has many potential applications, namely providing autonomous agents, both physical and virtual, with the ability to perceive emotions in human interlocutors, and therefore adapting its behavior. This ability can be transposed to ubiquitous computing environments, such as domotics, and direct advertising.

Considering the aeronautical simulation, an immersive realistic environment was achieved, potentiated by the use of 3D video eyeware with the definition and implementation of four distinct scenarios tightly coupled to the four quadrants of Russell's Model.

The conducted experimental protocol was carried out in a quiet controlled environment where subjects assumed the pilot's seat for approximately twenty-five minutes—including takeoff and landing—and the enunciated simulation variables were unconscientiously affected by the online assessed user emotions. It was found that those without fear of flight found the experience rather amusing, as virtual entertainment, while the others considered the simulation realistic enough to trigger an emotional response, verified by biometric readings mapped into Russell's Circumplex Model of Affect—arousal and valence levels.

Alongside with these outcomes, the results also suggested a trend to considerable pterygophobia mitigation, although further experimental sessions need to be conducted to fully support such statement.

The present document is organized as follows: in the next section a broad, yet detailed, revision of related work is depicted; in Sect. 3, the project is described in a global perspective but also by highlighting relevant particular system's modules; in Sect. 4 the conducted experimental session conditions are described; and, in the following section, the obtained results are presented; in the final section project conclusions are drawn and future work areas are revealed.

2 State of the Art

Due to the project's integration principle, this section is divided in three subsections: the first concerning automatic emotion assessment; the second regarding aeronautical simulation tools; and the final one reserved to pterygophobia treatments and approaches.

2.1 Automatic Emotion Assessment

Until a recent past, researchers in the domains related to emotion assessment had very few solid ground standards both for specifying the emotional charge of stimuli and also a reasonable acceptable emotional state representation model. This issue constituted a serious obstacle for research comparison and conclusion validation. The extreme need of such metrics led several attempts to systematize this knowledge domain.

Considering first the definition problem, Damásio states that an emotional state can be defined as a collection of responses triggered by different parts of the body or the brain through both neural and hormonal networks [6]. Experiments conducted with patients with brain lesions in specific areas led to the conclusion that their social behavior was highly affective, together with the emotional responses. It is unequivocal to state that emotions are essential for humans, as they play a vital role in their everyday life: in perception, judgment and action processes [7].

One of the major models of emotion representation is the Circumplex Model of Affect proposed by Russell. This is a spatial model based on dimensions of affect that are interrelated in a very methodical fashion [5]. Affective concepts fall in a circle in the following order: pleasure, excitement, arousal, distress, displeasure, depression, sleepiness, and relaxation—see Fig. 1. According to this model, there

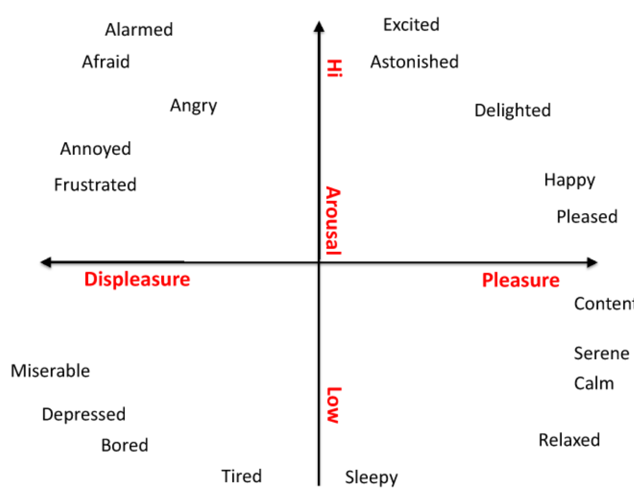


Fig. 1 Russell's circumplex model of affect [5]

are two components of affect that exist: the first is pleasure-displeasure, the horizontal dimension of the model, and the second is arousal-sleep, the vertical dimension of the model. Therefore, it seems that any affect stimuli can be defined in terms of its valence and arousal components. The remaining variables mentioned above do not act as dimensions, but rather help to define the quadrants of the affective space. Despite the existence of criticism concerning the impact of different cultures in emotion expression and induction, as discussed by Altarriba [8], Russell's model is relative immune to this issue if the stimuli are correctly defined in a rather universal form. Having this in mind, the Circumplex Model of Affect was the emotion representation abstraction used in the proposed project.

In order to assess Russell's model components, one ought to consider what equipment solutions were to be selected, considering, simultaneously, different features such as portability, non-invasive levels, communication integration and transparency and direct economical impact.

Emotions assessment requires reliable and accurate communication with the subject so that the results are conclusive and the emotions correctly classified. This communication can occur through several channels and is supported by specific equipment. The invasive methods are clearly more precise, however more dangerous and will not be considered for this study. On the other hand, non invasive methods such as EEG (Electroencephalogram), GSR (Galvanic Skin Response), ECG (Electrocardiogram), oximeter, skin temperature, respiration sensors, amongst others have pointed the way towards gathering together the advantages of inexpensive equipment and non-medical environments with interesting accuracy levels [9].

Some recent studies have successfully used just EEG information for emotion assessment [10]. These approaches have the great advantage of being based on non-invasive solutions, enabling its usage in general population in a non-medical environment. Encouraged by these results, the current research direction seems to be the addition of other inexpensive, non-invasive hardware to the equation. Practical examples of this are the introduction of a full set of non-invasive, low-cost sensors by Vinhas [11], Kim [12] and Katsis [13]. These particular studies demonstrate the versatility of such approaches as they range from multimedia storyline adaptations to large audiences—similar to theater or home entertainment—to standard controlled laboratory conditions and even high-noise environments such as emotion recognition in car-racing drivers. The usage of this kind of equipments in such diverse domains and conditions strongly suggests its high applicability and progressive migration towards quotidian handling.

Still taking into consideration equipment solutions, one must mention the critical importance of data communication features as this key component shall be wireless and contemplating the minimum amount of physical contact with the subject in order to minimize the intrusion effect and therefore distort the detected emotional state due to experience immersion loss.

For this study, the Nexus-10 hardware solution with temperature, GSR and Respiration Rate and Amplitude sensors shall be used and the data communication with the processing unit, fully described in Sect. 3, shall be based on wireless Bluetooth technology.

2.2 Aeronautical Simulation Tools

Simulation tools and simulated environments are used in virtually every field of research, providing researchers with the necessary means to rapidly develop their work, in a cost-effective manner.

In the aviation field, simulation is heavily used, ranging from multi-million dollar full simulators used to train professional pilots to freely available flight simulators used mainly for entertainment purposes and by aviation enthusiasts. In the past few years, these low-cost software simulators have achieved a higher level of realism, and some have even been certified by the FAA (Federal Aviation Administration) for pilot training, when used in conjunction with the proper hardware simulator. For instance, the X-Plane simulator is used by some simulator companies, such as Simtrain as the software basis for simulation [14].

There are two main simulator categories: Game Engines and Flight Simulators. In game engines, the most important aspect is an appealing visualization. Flight Simulators have a different approach: the main focus is the flight simulation itself. There is some focus on the visual aspect as well, but the main efforts are dedicated to aerodynamics and flight factors present in real world, thus trying to achieve as realistic a flight as possible [15].

The academic and business communities have also already begun to use these cost-effective tools, benefiting from what they have to offer [16].

The authors, after some consideration and analysis of available flight simulators and their distinctive characteristics, have chosen to use Microsoft Flight Simulator X (FSX) as the simulation environment. FSX not only provides a flexible, well-documented programming interface, called SimConnect, to interact with the environment, but also provides a very realistic visualization of the simulated world, with the possibility of using the recent DirectX 10 technology.

2.3 Fear of Flight

Several solutions are offered to treat pterygophobia, including medication, and some behavior therapies, including virtual reality solutions. These solutions are often used in conjunction with a more conventional form of therapy [17, 18]. One such example is Virtually Better, a clinic which offers

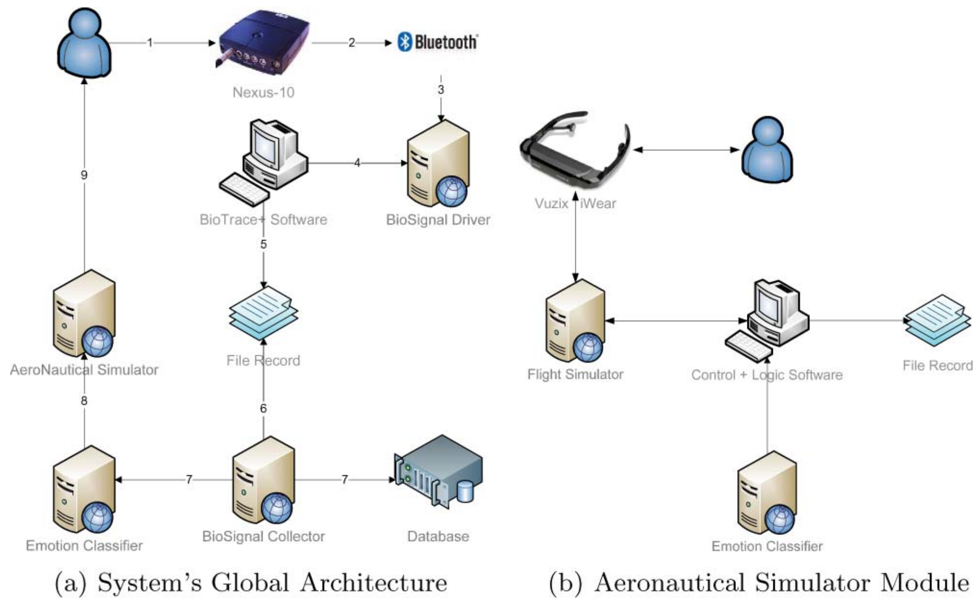


Fig. 2 System global architecture (**a**) and aeronautical simulator module (**b**)

several solutions based on virtual reality technology to support therapy in anxiety disorders [19, 20]. However, and despite having around fifty clinics worldwide—the majority located within the United States—it cannot offer its solutions to a very wide audience at an affordable cost. Some companies, such as Virtual Aviation, offer an even more realistic experience, using the same multi-million dollar simulators used to train professional pilots [21, 22]. Such companies have an even more limited geographical availability, and prohibitive prices—up to three thousand dollars for a session.

Though the authors are cautious regarding any conclusion about the psychological impact of this simulation tool, it is believed that this simulation, together with real-time emotional assessment, may have a solid impact in the treatment of pterygophobia, either by itself or combined with other forms of therapy.

Summarizing, the proposed solution not only presents an online Russell's Model emotion assessment tool, based on minimal-invasive Nexus-10 sensors, with complete communication and integration capabilities with third-party modules, but also provides a cost-effective solution for a virtual reality simulation that can be used for treating fear of flying.

3 Project Description

This section is fully devoted to project description from a logical and technical point of view. In order to better proceed with such intention, it was found useful to elaborate partitions to accommodate the global architecture delineation; emotion assessment module detailed description; and correspondent and particular aeronautical simulation component explanation.

3.1 Global Architecture

The system global architecture is based on independent and distributed modules, both in logic and physical terms. As depicted in Fig. 2(a), and following its enclosed numeration, it is possible to appreciate that biometric data is gathered directly from the subject by using Nexus-10 hardware. In more detail, temperature, GSR and respiration sensors are used—from these sensors, phalanx skin temperature, direct galvanic skin response and respiration amplitude and frequency rates are computed. In order to reduce the number of wires presented to the user, and therefore reduce the impact of signal measurement, thus conserving immersion sensation, the collected biometric data is, in real-time, transmitted by Bluetooth to a computer in the proximities running the adequate data driver. The next step is of the responsibility of BioTrace+ software, supplied with Nexus-10, and beyond providing a configurable interface for online signal monitoring, it records biometric data directly as an accessible text file.

The denominated BioSignal Collector software was developed in order to access the recorded data in real-time and make it fully available for further processing either by database access or online TCP/IP socket connection. In this last category, lies the Emotion Classifier, as it is responsible for online user's emotion state assessment—how this process is conducted is fully described in the next subsection. The continuous extracted emotional states are projected into the Russell's model quadrants and are filled as inputs for the Aeronautical Simulator. This system module, as a cycle of its own, as described in Fig. 2(b), and briefly depicted in the next paragraph.

The simulation endpoint, which serves as a running example, has a simple architecture. The main module communicates with the emotional endpoint and receives data from the emotion assessment module, indicating which of the four quadrants of the Russel's Model should be active. The module, in turn, communicates with the chosen simulator, changing its internal variables in order to match the desired quadrant, and as explained in more detail in Sect. 3.3. This module also produces a permanent accessible log file, with information collected from the simulator regarding location and attitude of the user plane. The simulator interacts with the user through immersive 3D video hardware, which allows the user to control the visualization of the simulation.

3.2 Emotion Assessment

The emotion assessment module is based on the enunciated 4-channel biometric data collected with Nexus-10 and accessed via text file readings at 10 Hz sample rate—which for the analyzed features is perfectly acceptable.

At the same frequency, emotional states are accessed and its definition is continuously uploaded to a database for additional analysis and third-party tools access. Directly related to the aeronautical simulation, the GUI also provides an expedite method to define the session's emotional policy, as it can be defined to force a specific quadrant, contradict or maintain the current emotional state or simply tour the four simulated scenarios.

In order to promote module's description efficiency, this subsection is divided in three parts, devoted to emotion model description; calibration and data fusion process; and dynamic scaling explanation.

3.2.1 Base Emotion Model

As referred, in the state of the art section, the followed emotion model option lied on Russell's Circumplex Model of Affect [5] that is illustrated in Fig. 1. This two-dimensional approach permits efficient, yet effective, online emotional assessment with none or residual historical data as it is based on single valence and arousal values. The key issue is not to determine the subject's emotional state when given a pair of valence/arousal values, but how to accurately resolve biosignals into valence/arousal pairs—this issue is addressed in the following subsection.

In order to anticipate the assessment of emotional data pair values, a normalization process is conducted, where both valence and arousal values are fully mapped into the $[-1, 1]$ spectrum. With this approach, emotional states are believed to be identified by Cartesian points in a 2D environment where, for instance, $(0, 1)$ represents a state of pleasure without arousal and $(-3/4, 3/4)$, high levels of fear, while $(0, 0)$ represents a neutral emotional state.

3.2.2 Calibration & Channel Fusion

Having into consideration the normalization process referred in the previous subsection, one ought to point out the importance of the calibration process. Although the 2D point $(-3/4, 3/4)$ represents a normalized defined emotional state, it can be achieved by an infinite conjugation of biosignals. This reality leads to the necessity of calibration and biometric channels fusion.

The first procedure consists in, for each subject and for each session—as the same individual can have distinct baselines and responses in dissimilar occasions—once the biometric data stream is enabled, pinpoint directly in the Russell's model representation, what is his predominant emotional state, through a self-assessment process. By performing this action, and hence considering the center of the plane as $(0, 0)$, it is possible to define a normalized emotional baseline point—identified as the bigger red dot in Fig. 3.

For each of the four channels taking into account for emotional state assessment an initial twenty percent variability is considered both in positive and negative relative variations. Whenever overflow is detected, the developed

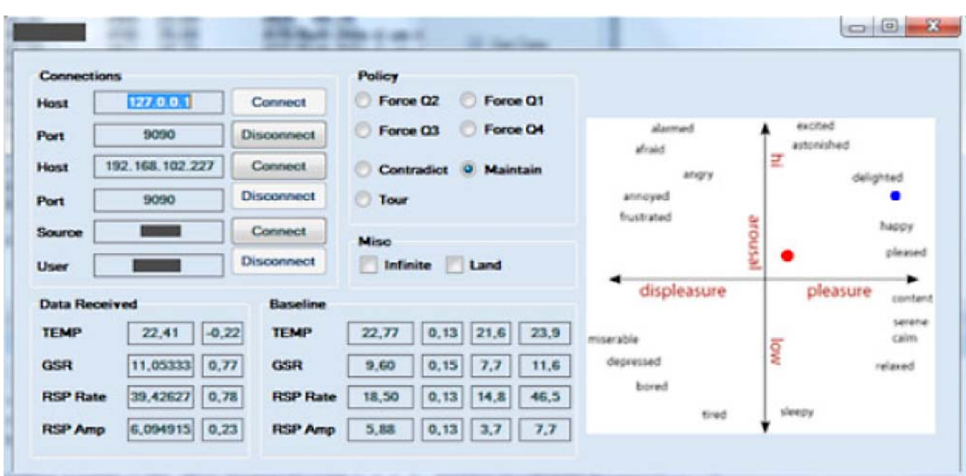


Fig. 3 Emotion classifier screenshot

dynamic scaling is activated as described in the following subsection.

It was considered for arousal values deviation, phalanx skin temperature and respiration rate and amplitude—higher values are reflected as positive deviations and lower values as negative ones. The three components were considered to have similar impact. For the valence values deviation, it was only considered the galvanic skin response. For this computation, the normalized baseline point is considered as reference.

The conjugation of such weights determine, in real-time, the normalized values of arousal and valence and therefore the current emotional state, identified by the GUI's smaller blue dot.

3.2.3 Dynamic Scaling

As a direct consequence of the emotional classification process illustrated in the last two subsections, one issue that emerges concerns either biosignal readings' overflow or underflow considering the user-defined baseline and initial tolerance allowed.

To overcome this potential system's limitation, it was engaged a fully dynamic scaling approach that consists in stretching the biometric signal scale whenever its readings go beyond the normalized interval of $[-1, 1]$. This scale update is conducted independently for each of the analyzed biometric channels. During this process, and whenever there is an overflow or underflow situation it is created a non-linear scale disruption resulting in greater scale density towards the limit breach.

$$c_1 Max = Math.Max(c_1 Max, Sample[c_1 Index]) \tag{1}$$

$$c_1 ScaleUp = \frac{1 - baseLineNorm.Axis}{c_1 Max - baseLineSample[c_1 Index]} \tag{2}$$

$$c = Sample[c_1 Index] - baseLineSample[c_1 Index] \tag{3}$$

$$c_1 Norm = baseLineNorm.Axis + c_1 ScaleUp \times c \tag{4}$$

In order to promote a more detailed understanding of the enunciated principle, one shall refer to the set of formulas listed in (1) through (4), where four steps are depicted concerning a situation where the collected data is greater the interval maximum. First, it is relevant to state that *Sample* [] is an array of biometric readings, while c_1 represents a particular biometric channel and $c_1 Index$ the channel's index; *baseLineSample* [] represents an array of normalized samples, while *baseLineNorm.Axis* is the first reading mapped into the axis. c_1 maximum value is updated by comparing the current reading with the stored maximum value—(1). If the threshold is broken, the system recalculates the linear scale factor for values greater than baseline neutral value, having as a direct consequence the increasing of the interval's density—(2). Based on the new interval definition, subsequent channel values shall be normalized accordingly—(3) and (4). In underflow situations, the process triggered is the corresponding dual of the depicted in the previous paragraph. With this approach, and in conjunction with dynamic calibration and data normalization, it becomes possible to the system to perform real-time adaptations as a result of user's idiosyncrasies and online biometric signal deviations, thus assuring continuous normalized values.

3.3 Aeronautical Simulation

The authors chose Microsoft Flight Simulator X (FSX) as the simulation environment, which not only provides a flexible, well-documented API (Application Programming Interface) to interact with the environment, but also provides a very realistic world visualization.

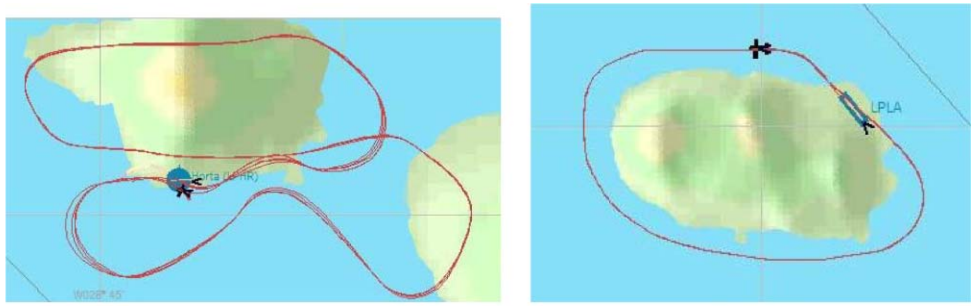
The desired emotional quadrant influences the simulation in three dimensions: weather, scenery and maneuvering.

The two quadrants characterized by a state of displeasure are associated with worse climacteric conditions, ranging from heavy thunderstorms, in the one related with fear (quadrant 2), to foggy cold fronts, in the one related with boredom (quadrant 3), leading to a rougher flight. The two quadrants characterized by the feeling of pleasure are associated with fair weather, producing a more stable flight.

The chosen global scenery is an archipelago, more specifically, the Azores archipelago, a set that can provide both a pleasant flight, with many enjoyable sightseeing moments, and an irregular one, crossing a major thunderstorm trying to keep the plane leveled.

For the two quadrants associated with high levels of arousal resultant of either excitement or fear (quadrants 1 and 2 respectively), the chosen itinerary takes the plane around an island, with many closed turns, at low altitudes, ranging from five to twenty-five hundred feet, including a low-altitude pass over the major city in the island. This roughly eight-shaped path also includes a brief incursion into a second island in close proximity to the first one, as shown in Fig. 4(a).

For the two quadrants associated with low levels of arousal, the chosen itinerary consists of an oval-shaped route around an island, as shown in Fig. 4(b). The turns in this route have a superior radius (resulting in smaller aircraft roll angle) and the altitude variations have smaller amplitude. As a result, the flight is experienced as a calmer one. Closely related to the route description is the maneuvering control. All maneuvers are done via the autopilot system present in the simulated aircraft. Given the waypoint the plane must follow, the desired heading is calculated, using the Great Circle formulas, and adjusting the heading to the magnetic declination of the area in which the flight takes place, this value is



(a) Route for Quadrants 1 & 2 (b) Route for Quadrants 3 & 4

Fig. 4 Routes for quadrants 1 & 2 (**a**) and 3 & 4 (**b**)

Fig. 5 Simulation environment influence summary

Quadrant	Russell's Model Quadrant	Scenery	Weather	Maneuvering
1	Upper Right	Eigth-shaped Fig. 4(a)	Fair Weather	Typical AP
2	Upper Left	Eigth-shaped Fig. 4(a)	Heavy Thunderstorms	Typical AP
3	Bottom Left	Oval-shaped Fig. 4(b)	Cold Fronts	Typical AP + Max Bank + Yaw Damper
4	Bottom Right	Oval-shaped Fig. 4(b)	Fair Weather	Typical AP + Max Bank + Yaw Damper

used as the input to the heading control of the autopilot system.

For the first route, typical autopilot controls are active, namely speed, heading and altitude, which controls the speed of the aircraft, the direction in which it should be flying and the altitude, respectively. As for the second route, two extra features are applied—maximum bank and yaw damper. The first limits the maximum roll angle of the plane during turns, while the second reduces rolling and yawing oscillations, making the flight smoother and calmer.

Figure 5 shows a summary table of how the simulation environment is influenced in each of the three dimensions for each quadrant. A mapping between quadrant numbers and the respective quadrants in Russell's model (see Fig. 1) is included.

4 Experimental Activities

In this section, the experimental settings and protocol definitions are described in detail, with special attention being paid to experimental sessions controlled environment features and the usage of the previously referred hardware solutions.

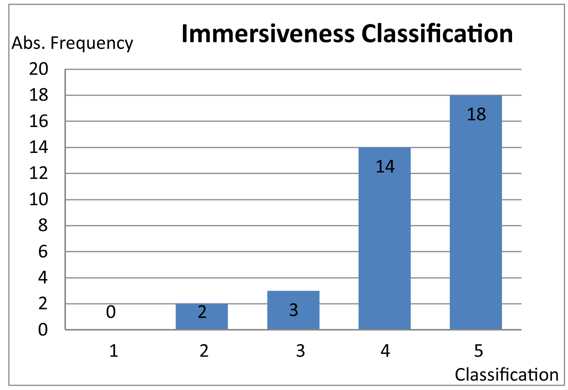
The experiments were conducted using two computers and a wide variety of hardware equipment, for both the biometric emotion assessment module and the simulation module. As for the first module, and as aforementioned, sensors for skin temperature, galvanic skin response and respiration rate and amplitude were used. Bipolar inputs have a gain of 19.5×, an accuracy of ±2% and a noise level ≤0.8 μV. The AUX inputs have an accuracy of ±2% and a Sampling resolution is of 24 bits, with frequencies of 2048 Hz and 128 Hz for bipolar and AUX inputs, respectively. As for the second module, and as previously stated, FSX was used as the simulation environment, providing both access to internal variables and a realistic visualization. In order to present the user with an immersive experience, 3D video hardware was used, in the form of virtual reality video eyeware. This equipment provides the user with a three degree of freedom head-tracker, allowing the user to experience the environment as if he was actually there.

After providing the authors with some background information to characterize the sample, the user was then connected to the biometric equipment, and an emotional baseline was established, as already explained in Sect. 3.2.2. Depending on whether the user suffered from pterygophobia or not, an emotional policy was followed by the operator. This policy, as already mentioned, ensured that users who suffered from this phobia would not be placed in a situation of high emotional stress, which could exacerbate the fear of flying, but would allow people who enjoy flying to experience extreme situations that could trigger an emotional response.

The experiments were comprised of three distinct sequential stages, as with actual flights. In the first phase, the plane takes off from an airport in one of the islands. The choice of the airport to takeoff from was primarily based

		Automatic Assessment			
		1st Quad.	2nd Quad.	3rd Quad.	4th Quad.
Users	1st Quad.	**31.2**	1.9	0.4	1.4
	2nd Quad.	3.3	**33.2**	0.8	0.2
	3rd Quad.	0.3	1.8	**9.8**	1.4
	4th Quad.	1.2	0.3	1.2	**11.6**

(a) Emotion Assessment Confusion Table



(b) Simulation Immersiveness Classification

Fig. 6 Emotion assessment (**a**) and simulation immersiveness (**b**)

on whether the subject stated to suffer from fear of flying. For individuals suffering from pterygophobia, the operator handling the emotional assessment module forced either the third or fourth quadrants, providing the subject with a calm takeoff and flight, as not to trigger an anxiety attack. For the remaining individuals, the operator forced one of the first or second quadrants, trying to obtain an increased amplitude of emotional responses. After takeoff, a series of closed circuits was performed, as already explained in Sect. 3.3. Finally, in the landing phase, the plane lines up with the selected airport, makes the approach and lands.

The experiments were conducted among thirty-seven subjects, twenty-four male and thirteen female, between the ages of twenty and fifty-six. Seven of the subjects stated that they had some level of fear of flying, while the remaining thirty declared not to be afraid of flying. Of the seven subjects suffering from some form of pterygophobia, four of them revealed that they have in fact never flown, with only three actually having suffered from the symptoms usually associated with this phobia.

After concluding the trial, the subjects were then asked to describe the experience, the emotional response that the simulation triggered, and if there were occasions when those reactions were stronger.

For the case of the seven subjects that stated to suffer from fear of flying, they were asked to repeat the experiment, as to obtain results that could enlighten the authors as to the possible usage of this tool in phobia treatment.

5 Results

In this section, the results that were obtained are presented and analyzed. These results shall be presented in a divided form, in three major categories: emotion assessment, simulation and the fear of flying.

In what concerns to emotion assessment, the validation model was based on user self-assessment, as for classification confirmation. After the experimental simulation ended, the user was asked to review an animation of the evolution of both the simulation and the emotional assessment and to confirm or refute those assessments. These results were assembled in two forms: the first concerning single emotions and specific regions of Russell's model, and the second concerning only the four major quadrants.

For the first method, a success rate of 77% was achieved. This method considered eight specific regions in Russell's circumplex model of affection, namely excited and happy for the first quadrant; afraid and frustrated for quadrant 2; miserable and bored for quadrant 3; and sleepy and calm for the fourth quadrant.

If only the four quadrants are considered, this success rate increases to 86%. Figure 6(a) shows the confusion table with the percentages of automatic assessment versus user self-assessment for each quadrant.

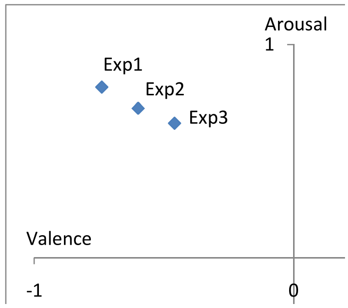
One additional result that can be seen by observing the table above is that users tend to locate their emotional states in the first and second emotional quadrants. Another aspect to consider is that the automatic emotion assessment has a lower rate of failure for opposite quadrants.

As for the simulation part of the experiment, users were asked to describe their experience, and to classify, in a scale of one to five, the level of immersiveness of the simulation environment. The results shown in Fig. 6(b) show that the majority of the individuals considered the environment to be highly immersive, with an average classification of 4.3 out of five.

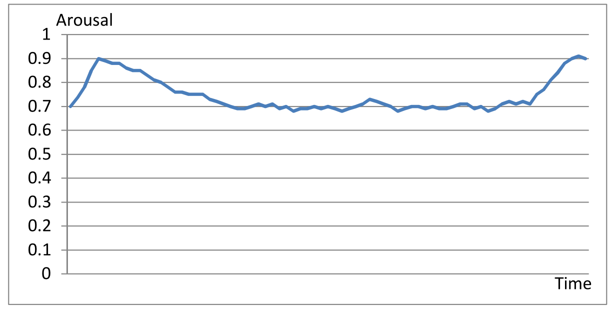
These results are supported by the subjects' emotional response to the change of the desired simulated quadrant by the emotional assessment module operator, confirming that the simulation environment triggers emotional responses.

Regarding the subjects suffering from pterygophobia, who repeated the experiment, some interesting results were

Fig. 7 Pterygophobia-suffering subjects' emotional trend (**a**) and average arousal levels (**b**)



(a) Emotional Trend



(b) Average Arousal Levels Throughout Simulation

obtained. One particular outcome that seems to support the fact that this kind of simulation can be used in the treatment of pterygophobia is depicted in Fig. 7(a), which shows the average emotional response for each of the three conducted experiments (the image shows the upper left part of Russell's Circumplex Model of Affect). As can be seen, the second and third experiments show an emotional response that tends to move away from the extreme end of the second quadrant, denoting a reduction in the levels of fear registered in the subjects during the latter experiments.

The first and third stages of the experiment are the ones traditionally associated with higher levels of apprehension and anxiety among passengers who suffer from pterygophobia, a fact that was confirmed by the experimental results. Six of the seven subjects that indicated suffering from fear of flying also stated, either before the experience or after it, that takeoff and landing are the most stressful moments, and the data collected by the emotional assessment module corroborates this fact, indicating higher stress levels during these stages.

Figure 7(b) shows the average arousal level measured during the initial experiments conducted among individuals suffering from pterygophobia (the x-axis being the duration of the experiment and the y-axis the average of the normalized values of arousal, as explained in Sect. 3.2). As can be seen, higher arousal levels were registered during the initial and final stages of the simulation, which represent takeoff and landing, respectively.

6 Conclusions and Future Work

In this section, the study's conclusions are drawn based on the results presented in the previous section. Based on the proposed and achieved project's objectives, the main future work areas that are to be further exploited will be pointed out.

Considering the project's conclusions, they shall be presented in four main categories: architectural, emotional assessment, simulation accuracy and immersion, and pterygophobia treatment influence.

Regarding the first topic, the complete distributed system architecture with both logic and physical module separation, proved to be reliable and efficient. This approach enabled total independence between biometric data collection, data processing and simulation related computation. It also provided database collection of both raw biometric channel values and semantic emotional state information for future analysis and validation, improving the system's openness.

At a more significant level, the emotional assessment layer reached high levels of accuracy, as the depicted results show. Through the previously detailed validation process, 77% of the classified emotional states were believed to be correct by the subjects. If classification is simplified to just Russell's model quadrant determination, this value reaches 86%, which supports the conclusion of an effective emotional assessment process. Still in this category, it is worth to mention the on-the-fly classification procedure that practically suppresses the need to long baseline data gathering and user identification as this baseline evaluation is performed by the user at any given time and can be adjusted. Also the dynamic scaling found itself useful in order to correctly accommodate outsized signal deviations without precision loss.

In what regards the aeronautical simulation, it is fair to state that all projected goals where completely fulfilled as users confirmed their immersion sensation either by self-awareness or biological recorded response. It is believed that the usage of 3D glasses as display device played a particularly important role in creating the appropriate environment. Also the defined scenarios, with distinct weather conditions, geographical context and maneuvers smoothness, lived up to challenge, as they generally triggered the desired emotional responses. Considering the economical cost of both the simulator and the virtual reality video eyeware used to provide the user with this immersive simulation environment, as well as the high immersiveness level reported by the test subjects, it is also reasonable to conclude that more economically viable simulators can be used in some less demanding environments, such as in the treatment of phobias.

As previously mentioned, the results seem to suggest that a significant mitigation of the symptoms of pterygophobia was achieved among the subjects that referred at least some level of fear of flying. However, additional trials would have to be conducted, with a larger sample, in order to fully backup this conclusion. In spite of this, fear of flying is due from a variety of more specific fears (such as fear of heights, fear of confined spaces, fear of speed and others), and as such, more focused tests should be devised, targeted at each of those particular phobias, for the sake of analysis accuracy.

In spite of the project's overall success, several improvement opportunities, in various domains, have been identified. Having this in mind, it has been found extremely useful, for future system's versions to include, in the emotional assessment engine, additional biometric channels, such as ECG, BVP (Blood Volume Pulse) and even EEG. This signals integration would be fairly transparent and straightforward as the current data fusion process and the emotional base model support that kind of enhancement. Still concerning the emotional assessment module, one shall mention the possibility to test Russell's model expansion to 3D by adding a dominance axis.

Regarding the aeronautical simulator, it would be interesting to define and test more navigation scenarios with fully automated and dynamically configured take-off and landing situations. It would also be useful a more transparent and smooth transition between contexts, especially between quadrants characterized by high levels of arousal and those with low levels of arousal.

Considering the fear of flight mitigation, although the collected results support such allegation, the reduced number of analyzed subjects that stated to suffer for pterygophobia does not allow serious statements of this approach success. Precisely as a consequence of this fact, it shall be engaged, as a next step, a broader study with a noteworthy sample specifically targeted to assess the success of the proposed system.

As a final project summary, one shall pinpoint the fact that the proposed system has a dual application as it can be interpreted as a complete entertainment system with user emotional awareness that continuously adapts the multimedia content accordingly to user's states for those without fear of flight and a more solemn approach as a phobia treatment auxiliary.

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References

1. Kozima H, Michalowski MP, Nakagawa C (2009) A playful robot for research, therapy, and entertainment. Int J Soc Rob 1(1):3–18
2. Kim J-H, Jeong I-B, Park I-W, Lee K-H (2009) Multi-layer architecture of ubiquitous robot system for integrated services. Int J Soc Rob 1(1):19–28
3. Mayo Clinic (2008) Phobias. Available online at http://www.mayoclinic.com/health/phobias/DS00272/DSECTION=symptoms. Accessed December 2008
4. Stoller G (2006) Fear of flying can cripple workers. USA Today, March 2006. Available online at http://www.usatoday.com/educate/college/business/articles/20060326.htm. Accessed December 2008
5. Russell JA (1980) A circumplex model of affect. J Personal Soc Psychol 39:1161–1178
6. Damásio AR (1998) Emotions and the human brain. Department of Neurology, Iowa, USA
7. Damásio AR (1994) Descartes error: emotion, reason and human brain. Europa-América
8. Altarriba J, Basnight DM, Canary TM (2003) Emotion representation and perception across cultures. In: Lonner WJ, Dinnel DL, Hayes SA, Sattler DN (eds) Read in psychol and cult. Center for Cross-Cultural Research, Western Washington University, Bellingham (Unit 4, Chap 5)
9. Benovoy M, Cooperstock J, Deitcher J (2008) Biosignals analysis and its application in a performance setting—towards the development of an emotional-imaging generator. In: Proc of the first int conf on biomedic electron and devices (Biosignals 2008), pp 253–258
10. Teixeira J, Vinhas V, Oliveira E, Reis LP (2008) Emotion assessment tool for human-machine interfaces—using EEG data and multimedia stimuli towards emotion classification. In: Int conf on signal process and multimed appl (SIGMAP 2008), pp 185–188
11. Vinhas V, Oliveira E, Reis LP (2008) Realtime dynamic multimedia storyline based on online audience biometric information. In: KES intell interact multimed syst and serv (KES IIMSS), pp 545–554
12. Kim J, André E (2008) Multi-channel biosignal analysis for automatic emotion recognition. In: Int conf on bio-inspired syst and signal process (Biosignals 2008)
13. Katsis C, Katertsidis N, Ganiatsas G, Fotiadis D (2008) Towards emotion recognition in car-racing drivers: a biosignal processing approach. IEEE Trans Syst Man Cybern, Part A, Syst Hum 38(3):502–512
14. Simtrain LLC (2008) Available online at http://www.simtrain.net/index.html. Accessed December 2008
15. Gimenes R, Silva DC, Reis, LP, Oliveira E (2008) Flight simulation environments applied to agent-based autonomous UAVs. In: Int conf on enterp inf syst (ICEIS 2008), pp 243–246
16. Lewis M, Jacobson J (2002) Game engines in scientific research. Commun ACM 45(1):27–31
17. Kahan M, Tanzer J, Darvin D, Borer F (2000) Virtual reality-assisted cognitive-behavioral treatment for fear of flying: acute treatment and follow-up. Cyberpsychol Behav 3(3):387–392
18. da Costa R, Sardinha A, Nardi A (2008) Virtual reality exposure in the treatment of fear of flying. Aviat Space Environ Med 79(9):899–903
19. Anderson P, Jacobs CH, Lindner GK, Edwards S, Zimand E, Hodges L, Rothbaum BO (2006) Cognitive behavior therapy for fear of flying: sustainability of treatment gains after September 11. Behav Ther 37(1):91–97
20. Rothbaum BO, Anderson P, Zimand E, Hodges L, Lang D, Wilson J (2006) Virtual reality exposure therapy and standard (in vivo) exposure therapy in the treatment for the fear of flying. Behav Ther 37(1):80–90
21. Virtual Aviation (2008) Available online at http://www.virtualaviation.co.uk/. Accessed December 2008
22. Bird S (2005) You're cleared for take-off—how to tackle a fear of flying on a virtual plane. The Times. Available online at

http://www.timesonline.co.uk/tol/life_and_style/health/features/article549165.ece. Accessed December 2008

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